whitepaper

SUPERCAPACITORS & UPS SYSTEMS

INTRODUCTION

Also known as an ultracapacitor, a supercapacitor is a high power density energy storage system that is becoming increasingly viable as an alternative to batteries in uninterruptible power supplies (UPS) requiring short autonomy times.

Supercapacitors have been an established backup power source for years in applications such as wind turbine generators and mobile telecommunications base stations, along with a variety of other electronic devices and industrial machinery.

In the UPS market, however, the traditional sealed lead-acid (SLA) battery remains dominant. While SLA batteries have well-known qualities, their drawbacks are familiar too: a relatively short lifespan, susceptibility to unexpected failure, and difficulties with recycling due to their toxic components.

As supercapacitors continue to mature and their upfront costs become less prohibitive, they offer a viable alternative.

They are suitable solutions across a diverse range of environments including data centres, hospitals, and manufacturing facilities that require short-term power (up to 30 seconds) before they can transition to other backup power sources such as generators or fuel cells.

WHAT'S THE DIFFERENCE BETWEEN A CAPACITOR AND A SUPERCAPACITOR?

A standard capacitor is a key component in any UPS system, helping to smooth, filter, and store energy.

A typical UPS unit includes dozens of different capacitors in both the power section and at the printed circuit board level (PCB). They range in size from a thimble or miniature drinks can through to a tube of Pringles.

A capacitor contains a pair of flat conducting surfaces – normally electrodes or metallic plates – enclosed in aluminium or chromium-plated cylinders, along with a dielectric medium that separates the two surfaces.

When a capacitor is charged, positive charges from one of the plates react with negatives on the other, creating an electric field which polarises the dielectric.

This forces the molecules to line up in the opposite direction to the field and reduce strength, which enables the plates to store more charge at a given voltage.

While supercapacitors work broadly in the same way as conventional ones, they differ in two fundamental ways.

Firstly, their plates cover a much larger surface area as their metal is coated with a porous substance such as activated carbon, which enables them to store much more charge.

In addition, the distance between the plates is smaller as the separator works differently to a conventional dielectric. In fact, there isn't a dielectric as such in a supercapacitor – the pairs of electrolyte-soaked plates are separated by a thin insulator made of carbon, paper, or plastic.

When the supercapacitor's plates are charged up, an opposite charge forms either side of the separator creating an electric double-layer.

This layer can be just one molecule thick, significantly thinner than the dielectric in a standard capacitor, where the thickness ranges from a few microns to a millimetre.

The amount of charge a capacitor or supercapacitor can store – measured in farads after the physicist Michael Faraday – is influenced by the thinness of the separator and the surface area of the plates.

The bigger the surface area and the less distance between the plates, the higher the capacitance.

With its bigger plates and electric double-layer, supercapacitors have a much higher power density than a conventional capacitor and can store as much as 10,000 times more energy per unit.

USING SUPERCAPACITORS WITH A UPS

A SuperCaps UPS system uses supercapacitors in place of the traditional sealed lead-acid batteries, either incorporated into the chassis itself or housed in an external cabinet.

Using supercapacitors in a UPS system requires several changes to both the electronics and the firmware controls inside the unit. This enables the system to manage the differing charge/discharge cycles and optimises the supercapacitors' operating life.

Due to their high power density compared to batteries, a SuperCaps UPS tends to require a smaller footprint than the typical battery-backed solution. On the flip side, the autonomy will be very short in comparison to a conventional UPS with batteries setup.

SUPERCAPACITORS VERSUS BATTERIES

Advantages Of Using Supercapacitors

- **Higher power density**

While supercapacitors have a lower energy density than SLA batteries, their power density is up to 100 times greater. This means supercapacitors release energy far, far quicker, while they also take a shorter time to recharge. The higher power density also ensures supercapacitors have a more compact footprint than a typically bulky and weighty battery installation.

- **Longer lifespan**

UPS batteries tend to have a 5 or 10-year design life, but in reality, will need replacing in year 3-4 or 7-8 of service life, respectively. In optimum conditions, a supercapacitor has an estimated life of 1 million cycles, meaning it can have up to a 15-year lifespan.

- **Reduced maintenance costs**

Supercapacitors don't need replacing as frequently as UPS batteries do. Neither do they require as much routine maintenance or expensive battery monitoring systems.

- **Wider operating temperature range**

SLA batteries perform best at an optimum operating temperature of 20-25oC. It is generally accepted that battery service life halves for every 10oC above this recommendation. Supercapacitors are not as sensitive to higher temperatures though. Similar to the electronics in the UPS itself, they can perform in temperatures up to 40oC without any significant derating or degradation. This reduces the need for expensive and energy intensive air conditioning and can lower cooling thresholds in server rooms. It also makes SuperCaps UPS a suitable option for harsher industrial environments.

- **No toxic or flammable components**

Unlike SLA batteries, supercapacitors aren't made using any toxic, corrosive, or flammable materials, so have a relatively low environmental impact. This also significantly reduces the removal and recycling costs.

Disadvantages Of Using Supercapacitors

- **Lower energy density**

Batteries can still hold up to 20 times the energy. This lower energy density means that supercapacitors do need frequent recharging, although this shortcoming is somewhat overcome by its near infinite cycle life (i.e. up to 1 million cycles).

- **Higher Initial Costs**

Even though supercapacitors are becoming a more mainstream solution, they still remain more expensive than a traditional UPS and battery set, mainly because of the high cost of materials such as carbon and graphene.

UPS APPLICATIONS USING SUPERCAPACITORS

Thanks to their high power density and rapid discharge capabilities, supercapacitors are ideally-suited for applications prone to short-duration power peaks or disruptions that last for just a few cycles.

For mission-critical sites such as a data centre or factory utilising sophisticated automated production processes, a generator set supported by a SuperCaps UPS providing short autonomy offers an efficient and effective solution.

In addition, supercapacitors' wider tolerance to ambient temperatures than SLA batteries makes them an alternative in harsh environments where high operating temperatures are unavoidable.

Other potential uses for supercapacitors include:

- **Renewable energy:** batteries used to store energy in photovoltaic solar installations require replacing every 3-7 years as their performance deteriorates. Because supercapacitors charge and discharge more quickly and support multiple cycles, they can last up to 15-20 years.
- **Hospital diagnostic equipment:** many radiological devices are characterised by short-term power absorptions – i.e. the examination time – interspersed with longer periods of more modest absorption. Using high-capacity supercapacitors enables any power peaks caused by the load to be effectively contained and therefore not being passed onto the incoming mains supply. This reduces the need to oversize supplies and onsite generation.
- **Regenerative braking on trains:** when trains brake, the kinetic energy can be fed directly into the main driving line that powers the vehicle as it subsequently accelerates. Supercapacitors ensure any excess energy doesn't go to waste by storing it so it can supply other critical loads.

LOOKING TO THE FUTURE

As covered earlier in this white paper, the exceptional capacity of a supercapacitor is partly due to the larger surface area of its plates and its covering.

Activated carbon is currently the most used material for this. It does, however, have its voltage and geometric limitations.

As an alternative, much research work is focusing on the development of supercapacitors using nanotechnology.

Studies suggest it's possible to create prototypes composed of millions of microscopic filaments coated with materials capable of butterflying electrons much faster, which reduces recharge times, or coated with capacitive nanomaterials that provide superior density.

The overall aim is to develop a new structure of nanotubes capable of increasing a supercapacitor's energy density whilst guaranteeing the same power characteristics (i.e. high density, long lifespan, rapid charge/recharge).

As this research continues apace, many in the industry predict supercapacitors will claim up to 50% of today's market share of lithium-ion applications within the next 15 years.